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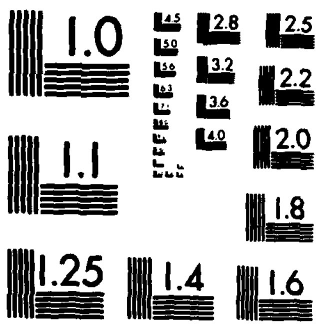

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US Army Corps
of Engineers
Construction Engineering
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TECHNICAL REPORT M-358
September 1984
Welding for Advanced Fastener Concepts

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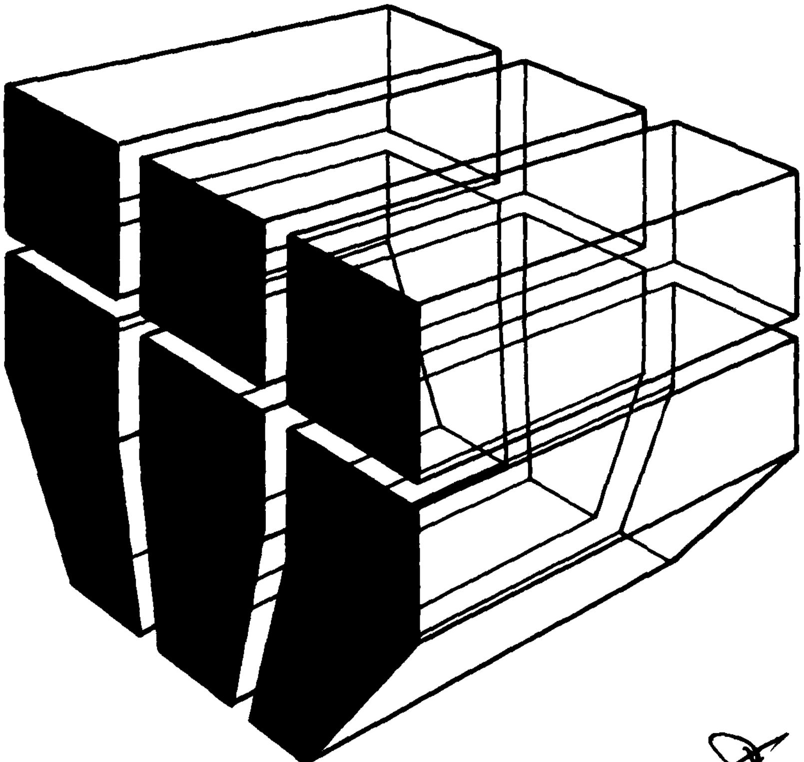
AD-A146 712

RECOMMENDED ALUMINUM PIPE WELDING PROCEDURES FOR CORPS OF ENGINEERS CONSTRUCTION



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An investigation of aluminum pipe welding techniques for field construction is documented. Information from the Aluminum Association and the Aluminum Company of America (ALCOA) was evaluated to see whether their methods would be feasible for use by the Army Corps of Engineers. These procedures were then tested on aluminum piping commonly used in Corps construction (6061-T6 and 3003-H18). The investigation verified that these methods were viable for military applications.

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The information gained during this investigation was used as a basis for recommending guidance on aluminum welding which can be incorporated into Corps of Engineers and Army welding guidance.

Among these recommendations are:

(1) Use of appropriate cleaning procedures on the joint before welding;

(2) Use of a push-button to control the weld contactor;

(3) Use of the gas tungsten-arc welding process;

(4) Use of the extended land joint configuration; and

(5) Use of current limits set by the Aluminum Association and ALCOA.

FOREWORD

This investigation was performed for the Directorate of Engineering and Construction, Office of the Chief of Engineers (OCE) under Project 4A762731AT41, "Military Facilities Engineering Technology"; Task Area B, "Construction Management and Technology"; Work Unit 034, "Welding for Advanced Fastener Concepts." The OCE Technical Monitor is Mr. George Matsumura, DAEN-ECE-G.

The work was done by the Engineering and Materials Division (EM), U.S. Army Construction Engineering Research Laboratory (USA-CERL). Dr. R. Quattrone is Chief of USA-CERL-EM.

COL Paul J. Theuer is Commander and Director of USA-CERL, and Dr. L. R. Shaffer is Technical Director.

CONTENTS

TABLES

FIGURES

RECOMMENDED ALUMINUM PIPE WELDING PROCEDURES FOR CORPS OF ENGINEERS CONSTRUCTION

1 INTRODUCTION

Background

Aluminum piping systems are being used to prevent corrosion in many special-purpose structures designed and built by the Corps of Engineers. However, while less expensive than steel, aluminum piping is much harder to weld. This has caused problems in field welding contracts when aluminum piping is specified and the contractors are unfamiliar with aluminum welding procedures. The Corps inspectors, who may be asked to provide guidance, may also have little or no experience with aluminum. Thus, while the inspector tries to resolve these problems, work can slow down or stop, which is very costly. This problem can be solved by providing the Corps inspector with basic information on aluminum welding parameters and accepted procedures.

Objective

The objective of this work was to investigate aluminum pipe welding techniques for field construction and to use this information as a basis for recommending guidance for Corps of Engineers aluminum welding processes and procedures.

Approach

Available literature on aluminum welding was surveyed and found to contain valuable procedures that could be incorporated into existing Corps guidance on welding. These procedures were tested to insure that their use in the type of construction used by the Corps would be feasible. The results of the tests were evaluated, and the appropriate parameters recommended for inclusion in Corps guidance.

Mode of Technology Transfer

It is recommended that the information in this report be used to update Corps of Engineers Guide Specification 15116, *Welding, Pressure Piping;* and Army Technical Manual 5-805-7, *Welding: Design, Procedures, and Inspection.*

2 EXPERIMENTAL PROCEDURE

Information Sources

Much information is available on welding aluminum pipe. The Aluminum Association (AA) has published and disseminated a great deal of information on this subject. One AA member company, the Aluminum Company of America (ALCOA), provides consulting services, so investigators for this project were able to obtain both information and actual experience with pipe welding at the ALCOA Technical Center.

Materials and Procedures

To verify the feasibility of using AA and ALCOA procedures in Corps construction, researchers tested the methods on types of aluminum pipe commonly used in military applications (Table 1). The gas tungsten-arc welding (GTAW) method was chosen based on recommendations of the AA and the

Table 1

Materials Listing and Specification Requirements
(Metric Conversion Factors: 1 in. = 25.4 mm; 1 ksi = 6.9 MPa)

Aluminum Association Designation	Specification	Yield Strength (ksi)	Ultimate Tensile Strength (ksi)	Nominal Size (in.)	Schedule
6061-T6	ASTM B241	40	45	1	10
		(15)*	(24)*	1-1/2	40
				2-1/2	40
				4	40
3003-H18	ASTM B241	27	29	2	40
		(7)*	(14)*	4	40
4043	AWS 510 ER 4043	–	–	1/8	–

*Minimum acceptable tensile strength levels across butt weld.

American Welding Society (AWS). The cleaning procedure was developed using AA-recommended procedures for preparing an aluminum weld joint. The joint design was taken from the recommended practice for pipe welds.

Testing Methods

Welded connections were made in the pipe using the GTAW process in the 1G, 2G, and 5G positions (horizontal-rolled, vertical-fixed, and horizontal-fixed positions, respectively). Each weld was radiographically inspected, with two exposures at 90 degrees from each other. The satisfactory welds were subjected to mechanical property testing. The smaller-diameter pipes were tested as-welded in tension, while two flat tensile specimens were machined from the 4-in.-diameter pipe and tested. The pipe specimens were tested using a SATEC Systems, Inc., 500,000-lb tension/compression machine. The 1/2-in.-(12.7-mm)-wide flat tensile specimens were tested using a Tinius-Olsen 20,000-lb tension/compression machine. The yield strength, ultimate tensile strength, and elongation were calculated and compared to the specification limits for each type of aluminum used.

3 WELD JOINT PREPARATION AND WELDING PROCEDURES

Weld Joint Preparation

Figure 1 shows the joint design used for all pipe welds except that of the 1-in. (25.4-mm) schedule 10 pipe, which was taken from practices recommended by ALCOA (see Figure 2). The land provides an area to burn in and allows for full penetration joints with little sag. The 1/16-in. (1.6-mm)-radius is critical in large-diameter pipe because this will help in the tie-in between the side wall and the extended land. For this investigation, the joint design was produced on a lathe in the machine shop; however, portable tools are available for field machining. The extended land-type joint used here is recommended for piping systems that will carry liquid and for heavier walled pipes (schedule 40 or larger). The beveled joint with a backing ring is recommended for other applications such as structures.

Sound welding practice requires that all foreign material be removed from areas to be welded. Paint or tar coatings should be removed from the weld area and from about 3 in. (76 mm) to each side of the weld area to allow full visual inspection. This also insures that the heat of welding will not decompose the paint or tar and cause a toxic atmosphere or interfere with making a good weld. Paint or tar should be removed by solvents, light wire brushing, or filing. All oil, grease, and dirt should be removed from the joint area before welding to avoid poor weld fusion and excessive porosity. Petroleum-based solvents are best for removing these contaminants. Naptha, toluene, and butyl alcohol are examples of good degreasing agents which evaporate quickly and leave little residue.

When aluminum is exposed to the ambient atmosphere, aluminum oxide forms on its surface. The oxide melts at 3700°F (2700°C), as compared to the base alloy, which melts at about 1200°F (642°C); thus, unless minimized before welding, it can act as a "stop-off" and prevent weld fusion. When aluminum is subjected to thermal treatments and weathering, the oxide becomes thicker. In some cases, an artificially thickened oxide or "anodizing" treatment is used as a paint base. These thick oxides can become insulators and prevent proper contact for the electrical current during welding. Thus, thick oxides must be removed from the weld area to permit proper weld fusion and also must often be removed in the area of the ground connection.

Oxides may be removed by grinding, sanding, or light wire brushing. Wire brushing is the preferred method, since grinding or sanding can imbed abrasive particles in the aluminum surfaces. Manual wire brushing is an acceptable technique for oxide removal. The wire brush should have stainless steel bristles and be free from oil, grease, and loose dirt. Power-driven wire brushes are also acceptable if light pressure is used. Heavy pressure between the power-driven brush and workpiece can imbed foreign material into the surface or create folds in the surface which entrap oxides, hydrocarbons, etc. The base material should be solvent-cleaned before wire brushing.

Weathering of bare aluminum used in marine applications can produce hydrated oxide films and water stains. The moisture in the oxide can cause excessive weld porosity unless removed before welding. Grinding or sanding followed by light wire brushing is the preferred method for removing these heavy oxide coatings.

Moisture on the surface of the base metal or filler wire will decompose in the arc, producing hydrogen. The hydrogen dissolves readily in the molten weld metal and is the major cause of weld porosity. Preheating the parts to be welded to a temperature no

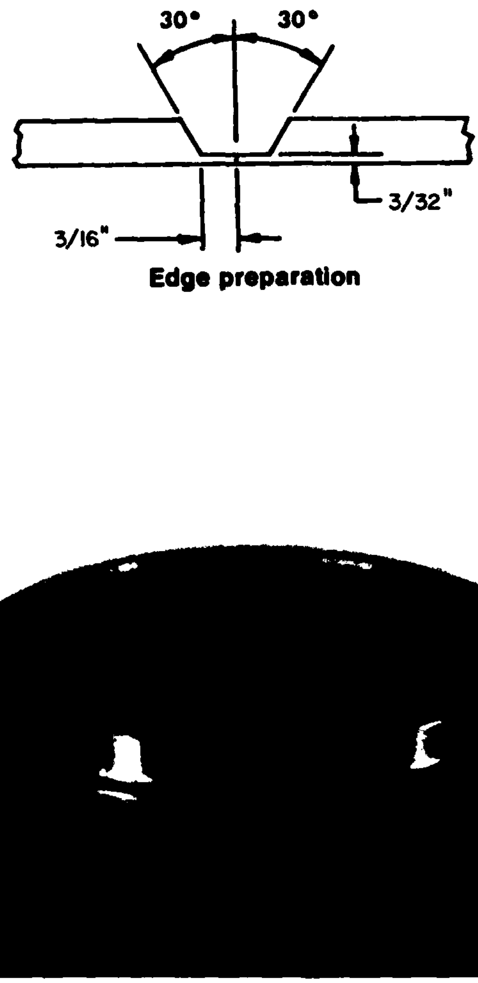
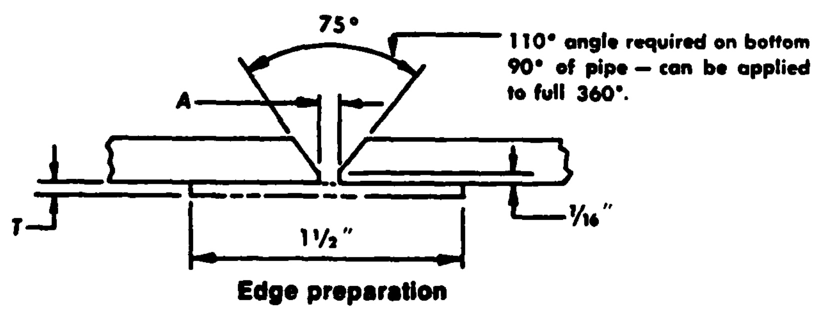


Figure 1. Details of joint design used for all schedule 40 pipe (top), and photograph of pipe end with joint configuration machined on.



A = 0 for no backing ring or removable backing ring

A = 1/4 in. maximum for integral backing ring

Figure 2. Joint design used for the 1-in. (25.4-mm) schedule 10 pipe.

higher than 250°F (120°C) before welding will drive moisture or condensation from the weld area. This thermal treatment can increase the oxide thickness, so wire brushing is required just before welding.

The final step in joint preparation is to cut a 1/16-in. (1.6 mm) chamfer around the inside diameter of the pipe, using a pocket knife or file. This will remove the oxide layer where the two joint parts meet and allow the metal to fuse without any oxide inclusions.

Welding Procedures

Manual welding of aluminum pipe requires use of the GTAW process with alternating current and manual filler metal additions. The pipe schedule, which is related to the pipe wall thickness, determines the weld current level to be used and therefore the tungsten electrode diameter. The position in which the pipe joint will be welded defines the current level to be used as well as the type of shield gas that will be used.

For welds made in the 5G (horizontal-fixed) position, a mixture of half argon and half helium is used at a flow rate of 60 cu ft/hr (1.68 m^3/hr). All other positions can be welded with pure argon shield gas. The welding torch should be equipped with a tapered gas nozzle rather than a swaged end nozzle. The preferred electrode material for AC welding on an extended land joint is pure tungsten; zirconated tungsten is the second choice. The pure tungsten produces a wider heat source and bead, so there is less penetration; there is also better control of the underbead contour.

Table 2 shows the welding parameters used to produce all the pipe weld joints. The interpass temperature was maintained between 120° and 150°F (49° and 66°C).

For field-welding aluminum pipe, it is recommended that the GTAW torch be equipped with an on/off push-button connected to the contactor of the welding power supply. Depressing the button closes the contactor, allowing current to flow across the arc. When the button is released, the contactor is opened and the arc is extinguished. The current level is set at the precise value for the weld and does not have to be controlled by a foot-pedal, thus eliminating some weld quality problems. This allows welding to be done in all situations without concern for where the foot-pedal has to be located. Also, the foot-pedal can be a problem if the welder must work on a ladder or lying down. Using the push-button, the weld can be finished by repeatedly pushing the button and feathering the end of the bead.

Figure 3 shows a typical finished weld joint. The toe of the weld has a smooth transition to the base metal. The area on each side of the weld bead shows the remnants of the cleaning action of the arc where the oxide has been removed.

4 WELD EVALUATION

The welding procedures that were used to produce the pipe specimens were taken directly from the Aluminum Association and included refinements supplied by ALCOA. It was found that the welding current limits set by these organizations produced acceptable welds with good penetration and usability. The extended land joint design provided easy access to the root, which allowed good control over weld bead contour and control over the amount of penetration and size of underbead reinforcement (drop-through).

Table 2

Welding Parameters for Aluminum Pipe Welds
(Metric Conversion Factors: 1 in. = 25.4 mm; °C = [°F−32][5/9].)

Pipe Size (in.)	Schedule	Aluminum Type	Position	Voltage	Current	No. of Beads	Interpass Temperature (°F)
1	10	6061-T6	5G	18	90	1	150
1-1/2	40	6061-T6	5G	18	120	2	150
2	40	3003-H18	1G	19	120	2	150
2-1/2	40	6061-T6	5G	19	130	2	150
4	40	3004-H18	1G	19	155	4	150

Figure 3. Typical metal weld made using gas tungsten-arc welding.

Table 3 shows the tensile testing results for the aluminum pipe joints. The smaller-diameter pipes were tested in as-welded condition. Solid metal bars were inserted in the ends of the pipe to prevent the pipe from crushing closed and possibly invalidating the test results.

Figure 4 shows a typical failure of the small-diameter pipe joints. The failure surfaces exhibit good ductility, as shown by the large amount of plastic deformation that occurred before failure. Another indication of the ductility is the final fracture surface, which is slanted at 45 degrees to the pipe's axis. The yield strength of the two specimens tested was just below the minimum 15 ksi (103.5 MPa) required. The tensile strength of the 6061-T6 pipe was above the minimum 24 ksi (165.6 MPa) required strength level.

The 2-in. (50.8-mm)-diameter 3003-H18 pipe was tested in the as-welded condition with slugs in the pipe ends to prevent crushing. The ultimate tensile strength of each pipe weld was above the 14-ksi (96.6 MPa) minimum required for this aluminum alloy. No yield strength data were determined for this specimen because the tension/compression machine used was not equipped to read a yield load. The failures showed good ductility with a lot of plastic deformation before failure occurred. The fracture surfaces were at 45 degrees to the pipe's axis.

Two flat tensile specimens were machined from each 4-in.- (101.6-mm)-diameter, schedule 40 pipe weld. All but one of the specimens broke in the base metal. Figure 5 shows a typical flat tensile specimen failure. Each specimen that broke in the base metal showed good ductility with elongations greater than 16 percent. The ultimate tensile strength of each specimen was well over the 14-ksi (96.6-MPa) minimum requirement. The yield strength of the specimens was well over the 7-ksi (48.3-MPa) minimum required for 3003-H18 aluminum. (One yield strength was not reported due to a failure of the recorder.)

Figure 6 shows a tensile specimen with a defect in the center of the weld caused by lack of fusion. The defect was too tight before testing to be picked up by radiography. Until enough plastic deformation occurred in the base metal which controlled the failure, the flaw was apparently below the critical size to cause failure. Figure 7 shows the fracture surface of the last tensile specimen. The arrow points to an area in which the lack of fusion was great enough to control the fracture location. This failure is marked by low ductility and the lack of a discernible yield point.

Table 3

Tensile Test Results
(Metric Conversion Factor: 1 in. = 25.4 mm; 1 ksi = 6.9 MPa)

Pipe Size (in.)	Schedule	Aluminum Type	Yield Strength* ksi	Ultimate Tensile Strength** ksi	Elongation %	Failure Location
1	10	6061-T6	14.2	25.8	5	Base Metal
1-1/2	40	6061-T6	14.9	24.4	–	Base Metal
			–	26.3	–	Base Metal
			–	26.4	–	Base Metal
2	40	3003-H18	–	16.0	22.9	Base Metal
			–	16.1	–	Base Metal
			–	16.7	18.7	Base Metal
			–	16.8	16.6	Base Metal
			–	16.3	16.6	Base Metal
4	40	3003-H18	10.8	17.0	18.9	Base Metal
			10.3	16.7	17.9	Base Metal
			–	17.2	18.6	Base Metal
			9.6	17.6	22.3	Base Metal
			11.0	17.1	21.6	Base Metal
			10.3	17.3	18.2	Base Metal
			10.3	17.9	20.5	Base Metal
			11.1	17.5	16.1	Base Metal
			9.6	17.1	16.7	Base Metal
				10.1	2.9	Weld Metal

*Acceptable values are 15 ksi for 6061-T6 and 7 ksi for 3003-H18.
**Acceptable values are 24 ksi for 6061-T6 and 14 ksi for 3003-H18.

Figure 4. Typical small-diameter pipe tensile test fracture showing the failure outside the weld in the base material.

Figure 5. Tensile specimen showing typical fracture with failure outside the weld metal.

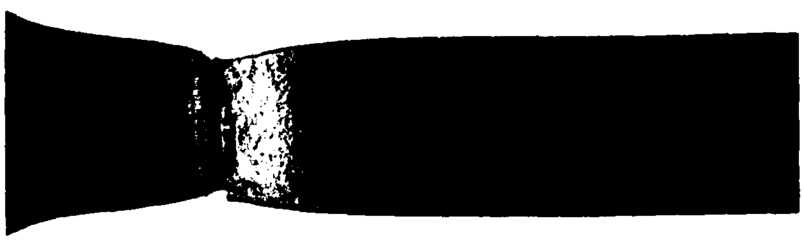


Figure 6. Failed tensile specimen showing centerline lack of fusion.

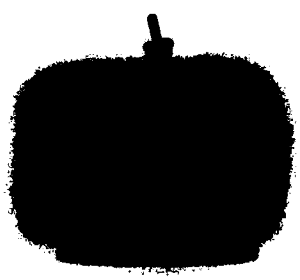


Figure 7. Fracture of failed tensile specimen showing area with lack of fusion (arrow).

5 CONCLUSIONS AND RECOMMENDATIONS

The following conclusions are based on the results of this work:

1. Use of GTAW process will provide sound welds in 3003-H18 and 6061-T6 aluminum pipe.

2. The extended land joint configuration for the 5G and 1G weld joints provides maximum control over weld drop-through and wide-wall fusion.

3. The use of the push-button to control the weld contactor can eliminate some weld quality problems by reducing the variance in the current caused by manual methods.

4. The current limits set by the Aluminum Association and ALCOA produce an acceptable weld with few control problems.

5. Use of the appropriate cleaning procedures can reduce defects in the weld that are a direct result of oxide, moisture, hydrocarbons, and dirt.

It is recommended that the aluminum welding methods of the Aluminum Association and the ALCOA be incorporated into guide specifications for welding procedures for Corps of Engineers construction.

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